CLIMATIC VARIABILITY AND DENGUE VIRUS TRANSMISSION IN CHIANG RAI, THAILAND

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ABSTRACT

Objective: The objective of this study was to assess the impact of climate variation on the dengue virus transmission in Chiang Rai, Thailand.

Materials and Methods: We obtained population – based information on monthly variation in monthly dengue cases and climatic factors. A time series analysis was conducted by using cross-correlation function and seasonal auto-regressive integrated moving average (SARIMA) modeling.

Results and Conclusions: Our findings indicate that rainfall and minimum temperature seem to have played an important role in the transmission of dengue in Chiang Rai. Such model may be used to assist public health decision – making and environmental health risk management. Early warning based on forecasts could assist in improving vector control, community intervention, and personal protection.

Key words: Dengue, Climatic, Seasonal auto-regressive integrated moving average, Time series, Cross – correlation function.

INTRODUCTION

Dengue fever is an arboviral disease in terms of morbidity and mortality,[1] caused by infection with one or more of the four dengue virus serotypes. Dengue virus is transmitted to human through the bites of infective female *Aedes* sp. (Diptera: Culicidae) mosquitoes.[2,3] Dengue is one of the most important mosquito – borne diseases in the world, especially in countries located within the equatorial zone where seasonal and geographical distributions are dependent on climate that is conducive to its transmission.[1,4] Concerns regarding the impact of global warming on vector – borne diseases[5,6] have intensified interest in the relationship between temperature and dengue fever incidence and include a focus on determining whether climatic factors alone can be used to indicate or predict variations in dengue incidence.[7] However, even if epidemiological surveys show that in endemic situations trends in incidence are generally driven by variations in seasonal climate, these changes in incidence depend on many parameters and the impact of temperature alone cannot be isolated easily from that of other climatic (e.g. rainfall, relative humidity) and non-climatic (e.g. immunity) factors.[8-12]

Dengue infection, including non-severe dengue and severe dengue,[3] has increased dramatically in recent decades. In the last 50 years, there has been a thirtyfold increase as well as geographical expansion of incidence to new countries, particularly in rapidly expanding urban and semi-urban areas in middle and low income countries where water storage and waste disposal services are limited.[3,13] An estimated 50 million dengue infections occur annually[3] and about 2,500 million people live in regions with the potential risk of dengue transmission.[2,14] In Thailand, dengue occurred first only in Bangkok in 1958, but soon spread to other areas.[15,16] In June 2007, dengue outbreaks occurred in Trat, Bangkok, Chiang Rai, Phetchabun, Phitsanulok, Kamphaeng Phet, Nakhon Sawan and Phichit.[3] At that time dengue incidence in Chiang Rai was the highest in Thailand with 464 cases.[3] Dengue is transmitted mainly by *Aedes aegypti* and possible *Ae. albopictus* in the tropical and subtropical regions of the world.[17] These mosquitoes are well adapted to the urban environment and successfully breed in containers where water is allowed to accumulate, such as discarded cans, bottles, plastic containers and tyres.[18,19]

Global climate change poses the threat of serious social upheaval, population displacement, economic hardships, and environmental degradation.[20-22] Human health could be influenced by increased variability and sustained changes in temperature, rainfall patterns, storm severity, frequency of flooding or droughts and rising sea levels.[21,23,24] The ecology, development, behaviour and survival of mosquitoes and the transmission dynamics of the diseases they transmit are strongly influenced by climatic factors (i.e. precipitation, temperature, relative humidity, wind, duration of daylight, storm severity, frequency of flooding or droughts and rising sea levels).[24-27] Changes in temperature, rainfall and relative humidity have potential to enhance vector development, reproductive and biting rates, shorten pathogen incubation period and encourage adult longavity.[6,28-31] In addition, changes in wind direction, velocity and frequency will have an impact on adult mosquito populations, affecting dispersal, survival and aspects of the general behaviour of many species.[6] The complex interplay of all these factors determines the overall effect of climate on the local prevalence of mosquito – borne diseases.[27]

In 1992 the Ministry of Public Health (MOPH) and the Ministry of Education began to integrate information about dengue into the primary school curriculum, and since 1998 vector control and health education specialists have worked throughout the country, applying larvicide and fogging during the epidemic season.[32] The intervention has not been sufficient for dengue control because high risks of dengue transmission continue to exist in several regions of Thailand.[3] Time – series methodology has been increasingly used in epidemiological research on infectious diseases, particularly in the assessment of health services.[33-40] Climatic variables (e.g. temperature, rainfall, and relative humidity) as potential predictors of dengue incidence have been examined in time series studies.[39,41-43] A few research findings are available on the effect of climatic variables on dengue transmission in Thailand[44,45] and rather limited study has been done in Chiang Rai.[46] Therefore, a better understanding of dengue outbreak prediction in Thailand is still needed. In this study, we used the time – series regression approach to examine the effect of climatic variability on the dengue incidence in Chiang Rai for the period of 1991 – 2009.

MATERIALS AND METHODS

Study area

Chiang Rai province is the northernmost province of Thailand with an average elevation of 580 m. Chiang Rai has an area of 11,678.37 km^2 with a human population of 1,129,701. The majority of the population is Thai with 12.5% of the population identified as members of various hill tribes. The province borders Myanmar on the north and Laos on the north and northeast (Fig. 1).[47] In Chiang Rai, the summer season is from mid-March to mid – May. The rainy season starts in mid-May and ends in mid – October. The winter season follows from mid – October to February. The average annual rainfall is 1354 mm. The average maximum and minimum temperatures are 31.5°C and 20°C respectively.[48]

Data Collection

We obtained the computerized data set on monthly-notified dengue cases in Chiang Rai for the period of 1991 – 2009 from the Bureau of Epidemiology, Department of Disease Control (DDC), MOPH. Thailand has had a well – established surveillance system for dengue since 1967.[46] All identified dengue cases are based on World Health Organization (WHO) clinical criteria.[3,46] A dengue case is clinically – diagnosed and laboratory – confirmed. The data were collected continuously and systematically from government (public) hospitals, provincial public health offices and health centers by the National Disease Surveillance (Report 506), Bureau of Epidemiology, DDC, MOPH, Thailand. The 506 Surveillance weekly summarized databases comprising information on the dengue cases such as gender, age, nationality and occupation. The data collection mechanism has been stable over time, and this routinely collected data can be used for analysing factors affecting the occurrence of dengue fever.

Climatic data obtained from the Northern Meteorological Center consisted of monthly max – min mean temperature, max – min mean relative humidity, max – min mean pressure, max mean wind speed, monthly rainfall, daily max rainfall, rainy days, evaporation, cloudiness, foggy day, hazy day, dew point and visibility.

Statistical Analysis

Spearman's correlation analysis was conducted to examine the relationship between monthly climatic variables and the dengue incidence. The dengue incidence was calculated from the number of dengue cases per 100,000 populations in Chiang Rai over the period of 1991 – 2009. We used a cross – correlation function to assess the degrees of correlation between climatic data and dengue incidence over a range of time lags from 0 to 2 months. A time lag was defined as the time span between a climatic observation and the incidence of dengue.[49]

The Seasonal Autoregressive Integrated Moving Average (SARIMA) model was used to estimate the independent contribution of each climate variable in this study as it was assumed that there was a dose–response relationship between the dependent variable and independent variables. Since there might be auto-correlations among both dependent and independent variables over time, the SARIMA analysis was performed to control for possible auto-correlations in the time – series data. A model was developed after the effect of auto-correlation had been removed by the SARIMA procedures. Three steps were undertaken in the modeling of the relationship between climate variation and the dengue transmission in Chiang Rai. First, SARIMA models were developed using the monthly incidence of dengue

Table 1: *Spearman correlation between climatic variables and dengue incidence in Chiang Rai at the lags with maximum coefficients, *Significant at the 0.05 level (two-tailed).*

Climatic variables	Spearman Correlation	
	ρ	Lag months
Max temperature (°C)	0.6332*	2
Min temperature (°C)	0.7792*	1
Mean temperature (°C)	0.6732*	1
Max relative humidity (%)	-0.4152*	2
Min relative humidity (%)	0.7471*	0
Mean relative humidity (%)	0.6557*	0
Max Pressure (hPa)	-0.6944*	1
Min Pressure (hPa)	-0.7149*	2
Mean Pressure (hPa)	-0.7423*	1
Max wind speed (Knots)	0.5696*	2
Mean wind speed (Knots)	0.4320*	2
Monthly rainfall (mm)	0.6224*	0
Daily max rainfall (mm)	0.4900*	0
Rainy days (d)	0.6863*	0
Evaporation (mm)	0.6928*	2
Cloudiness (0-10)	0.7505*	0
Fog (d)	-0.6547*	2
Haze (d)	-0.6147*	0
Dew point (°C)	0.7947*	0
Visibility (km)	0.6102*	0

as dependent variable and the monthly averages of climate variables as independent variables after seasonal difference was smoothed to make a drifting series stationary. Secondly, the goodness of fit of the models was checked for adequacy, using both time series (i.e. auto-correlation functions of residuals, which are defined as the differences between the actual values and the forecasted values) and classical tools (i.e. check for the normality of residuals).[50] Finally, the data between January 1991 and December 2008 were used to construct a SARIMA model, and the forecasting accuracy of this model was verified using the data between January and December 2009. Twelve predicted months were used to verify the SARIMA model.[51]

RESULTS

Monthly max – min mean temperature, min / mean relative humidity, evaporation, max mean wind speed, monthly rainfall, daily max rainfall, rainy days, cloudiness, dew point and visibility were positively associated with monthly dengue incidence notified in Chiang Rai over the study period with 0 – 2 months of lagged effect (Table 1). Monthly max / min / mean pressure, max relative humidity, foggy days and hazy days were negatively associated with monthly dengue incidence with 0 – 2 months of lagged effect (Table 1).

After cross – correlations adjusted for seasonality were performed, the dengue incidence was associated with monthly rainfall, daily max rainfall at lag of 0 – 1 month, min temperature at lag of 1 month, and evaporation at lag of 2 months (Table 2). The results of SARIMA model show that the incidence of dengue was significantly associated with monthly rainfall at lag of 0 month and minimum temperature at lag of 1 month (Table 3, Fig. 2). The SARIMA model was verified using the data over the period of January to December 2009 after the models had been constructed with the data compiled between January 1991 and December 2008. There was no significant autocorrelation between residuals at different lag ti-mes in SARIMA (SARIMA $(1, 0,0)\ (1,0,1)_{12}$) model (*Portmanteau* statistic Q_{25} = 17.225, χ_{24}^2 = 36.415, $p>0.05$; Fig. 3a, b). The predicted values and the actual incidence of dengue matched reasonably well (Fig. 4).

Table 2: *Cross – correlation coefficients between climatic variables and incidence of dengue in Chiang Rai, Thailand.*

Lag months	Rainfall	Daily max rainfall	Min temperature	Evaporation
0	0.266*	0.187*	0.110	0.033
1	0.238*	0.227*	0.139*	0.017
2	0.125	0.087	0.098	0.159*

*Significant at the 0.05 level (two – tailed).

DISCUSSION

The results of this study indicate that climatic variability is clearly associated with the dengue incidence. In particular, rainfall and minimum temperature seem to have played an important role in the transmission of dengue in Chiang Rai. The results indicate that an increase in rainfall and minimum temperapture is associated with an increase of dengue incidence. Daily maximum rainfall and evaporation is positively associated with dengue incidence but they fail to enter the best fitting predictive models.

Rainfall is one of the important elements for the breeding and development of mosquitoes.[52-54] Many studies have shown that rain plays an important role in dengue epidemiology.[45,52,55,56] Our results confirm previous observations and indicate that rainfall is one of the key predictors of dengue transmission. This could be because water not only provides the medium for the aquatic stages of the mosquito's life cycle but also increases the relative humidity and hence longavity of adult mosquitoes. Rain may prove beneficial to mosquito breeding if moderate, but it may destroy or wash out existing breeding sites and interrupt the development of mosquito eggs when excessive.[26,40,44,52,55,56] Increased rain may increase larval habitat and vector population size by creating a new habitat or increase adult survival.[26,57] In tropical areas in particular, extensive and continuous rainfall can delay the build-up of some mosquito species until late in the season and thus delay transmission.[6]

Temperature is an important environmental parameter with respect to enhancing vector development, gonotrophic cycle length, fecundity, time from emergence to first blood meal, biting rates, shortening pathogen incubation period and encouraging adult longavity.[6,8,28-31,57-65] In addition, temperature is also a crucial factor in the dynamics of

Table 3: *Regression coefficients of climatic data on the monthly dengue incidence rate in Chiang Rai, Thailand.*

Variables	*β*	*S.E.*	*t-Statistic*	*AIC*
Intercept	-12.719	4.289	-2.966*	1666.87
Rainfall at lag of 0 month	0.035	0.007	4.706**	
Minimum temperature at lag of 1 month	0.694	0.247	2.813*	

AIC: Akaike's information criterion, β: coefficients, S.E.: standard error.
*, **Significant at the 0.01 and 0.0001 level (two-tailed).

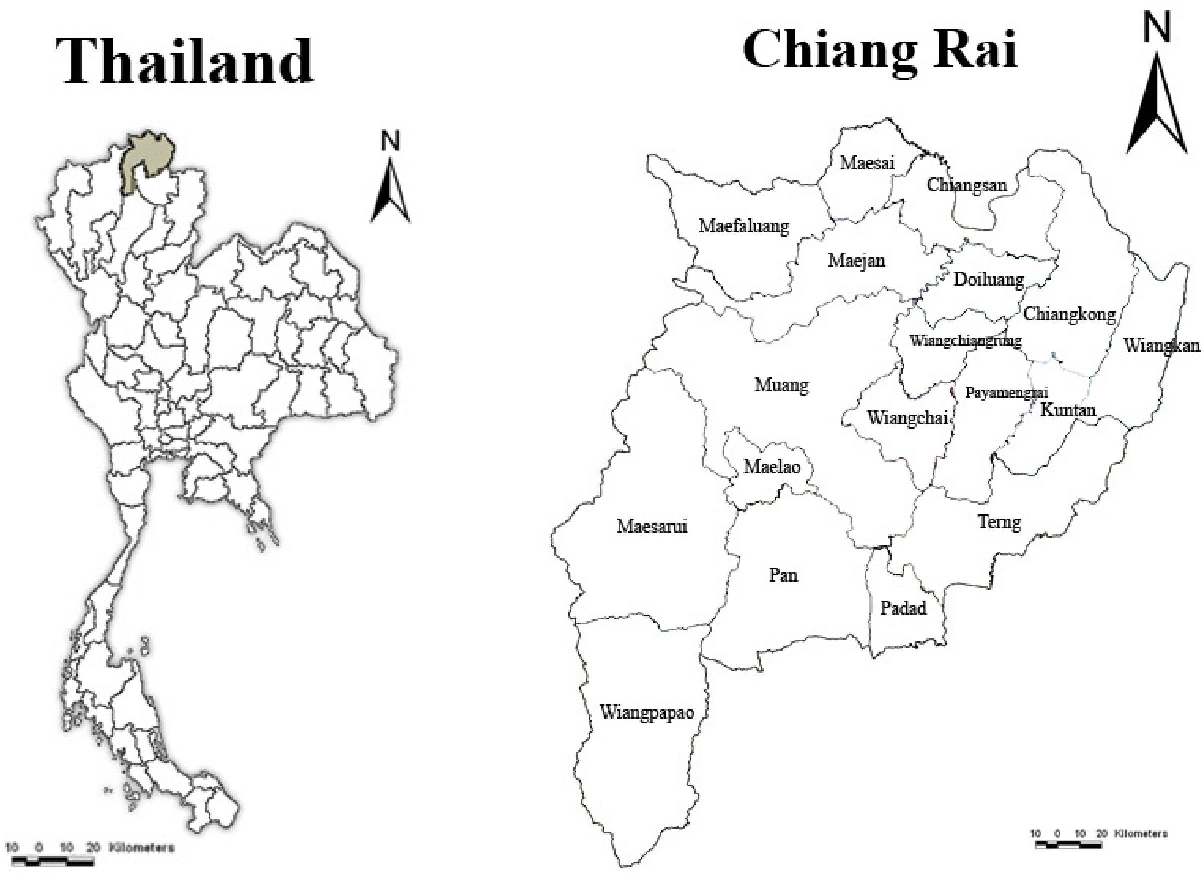

Fig. 1: *Map of Chiang Rai, Thailand.*

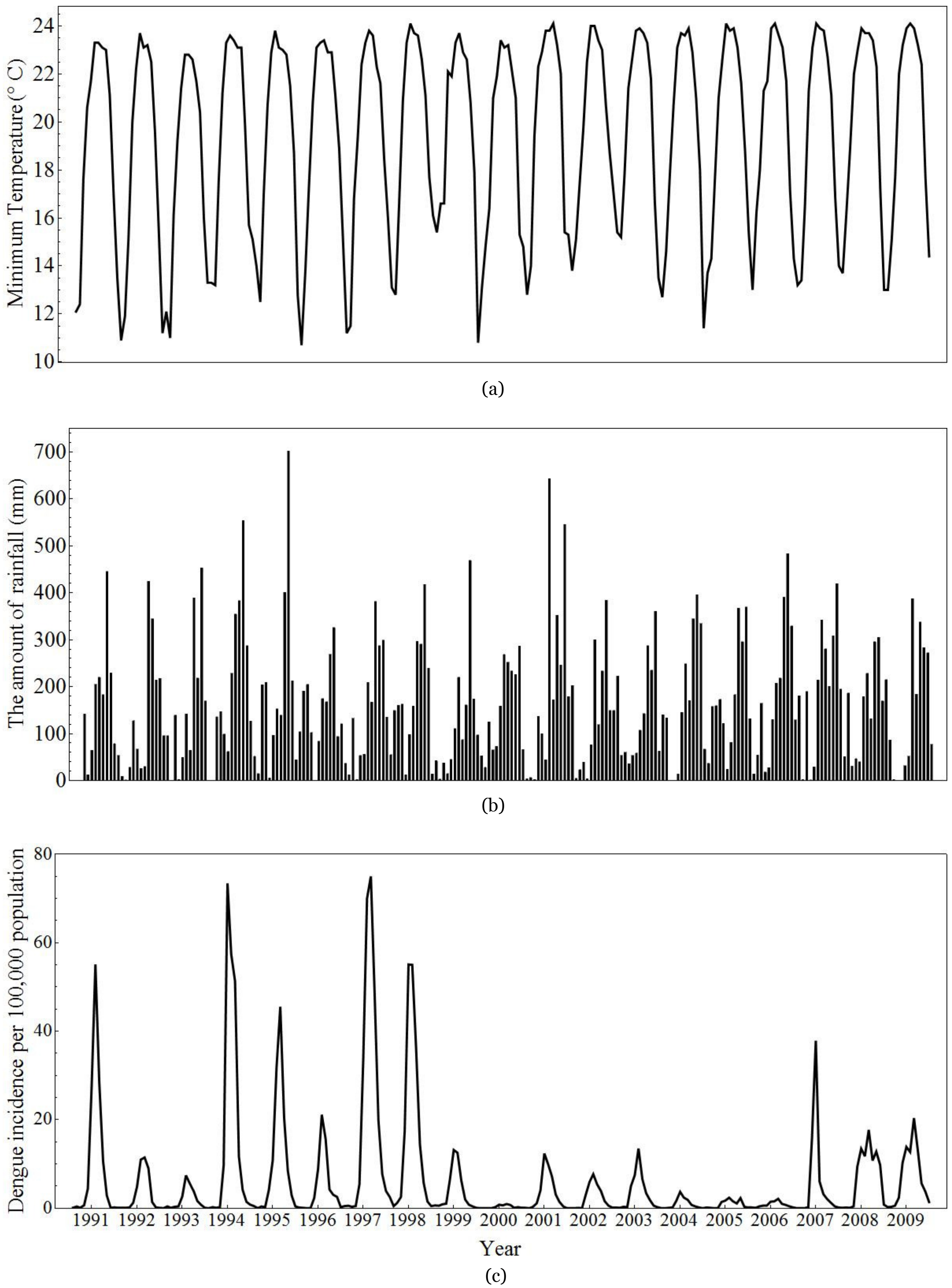

Fig. 2: *Minimum temperature (a), rainfall (b) and dengue incidence (c) in Chiang Rai, Thailand from 1991 to 2009.*

extrinsic incubation period (EIP) of dengue virus in *Ae. aegypti*, transmission. It can promote infective potential and produce more effective and more frequent transmission.[57,66-68]

Our study shows a positive correlation between monthly dengue incidences and minimum temperatures with 1 month lag effect. This result is in general agreement with the findings of other studies[39,40] that minimum temperature is a precipitating factor for dengue transmission. A rise in temperature, especially minimum temperature, enhances the survival chances of dengue virus and *Aedes* larvae and adults during winter. Consequently, it accelerates the transmission dynamics of dengue and spreads it into populations that are currently dengue free and immunologically naïve.[9,69,70]

Chiang Rai experiences relatively high temperature and humidity year round. Except for the winter season, most months in Chiang Rai record an average temperature higher than 18°C which is considered ideal for survival of mosquito vectors and amplification of viruses. Our data suggest that Chiang Rai with more than 11 months of temperature at ≥ 18°C has immense potential for sustaining the pathway for dengue fever infection. The threshold of minimum temperature for dengue fever virus survival is 11.9°C,[71] and virus will not amplify in vector when temperature is below 18°C.[8] Our results clearly support previous obser-

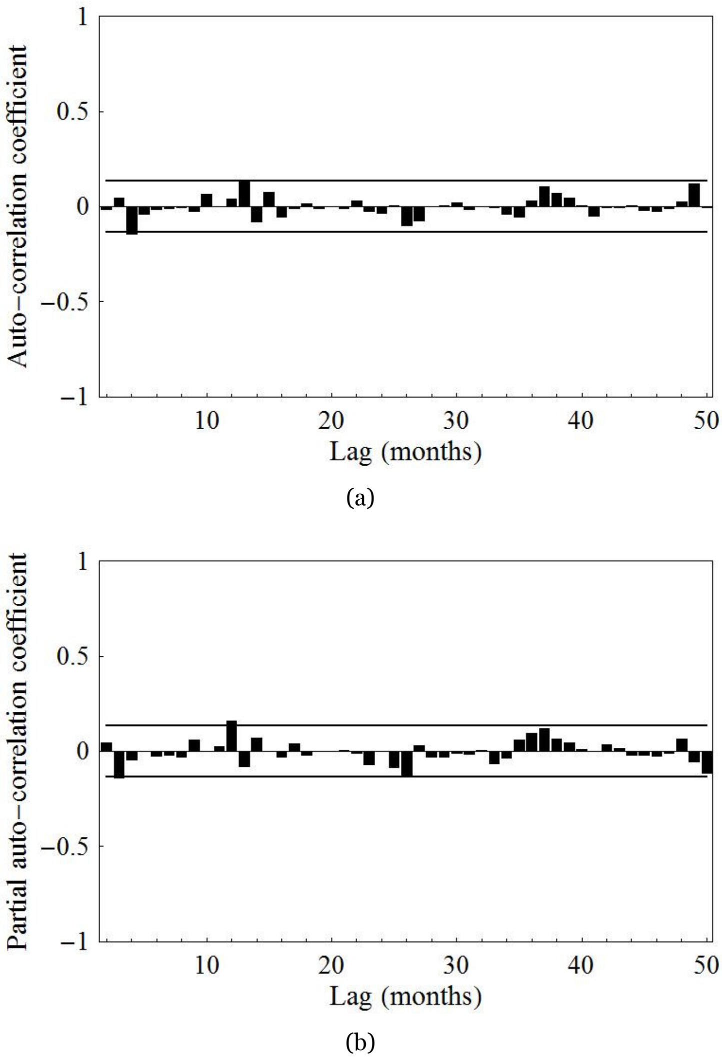

Fig. 3: *(a) Auto-correlation function (ACF) and (b) partial auto-correlation function (PACF) of residuals.*

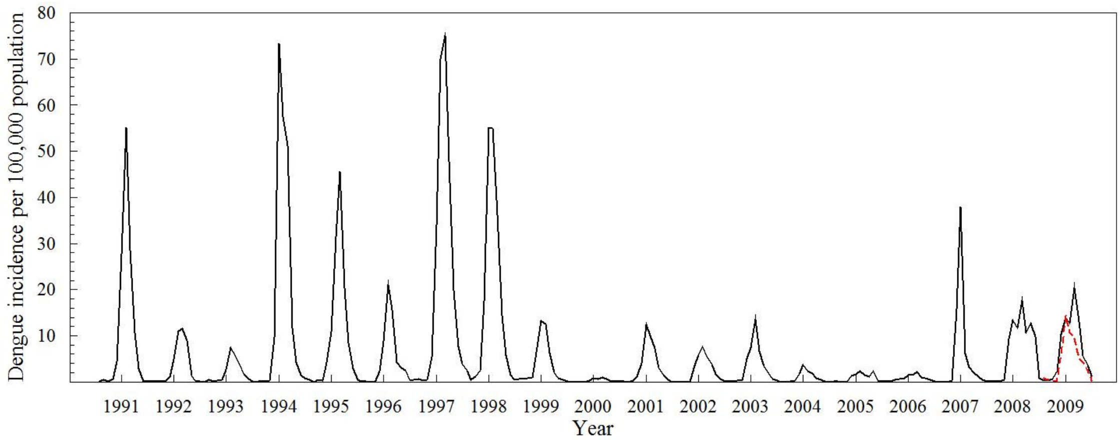

Fig. 4: *The actual monthly dengue incidence (solid line) from 1991 – 2009 and the predicted monthly dengue incidence (dashed line) in 2009 by the SARIMA model in Chiang Rai, Thailand.*

vations that any winter with more than 2 cold months in the season would most likely eliminate the vector and virus or disrupt the chain of transmission. Minimum temperatures in 1992, 1993, 1997, 1999, 2000, and 2004 dropped below the critical threshold for dengue virus to survive (i.e. 11.9°C). As a result, dengue incidences declined markedly.

In this study, the SARIMA model gives a good predicted dengue incidence in 2009 in Chiang Rai. This indicates that we could apply this SARIMA model to other provinces in Thailand as a predictor of dengue outbreaks. The SARIMA modeling has proved to be useful for interpreting and applying surveillance data in disease control and prevention.[37,72] However, the range of vector – borne disease is not determined only by climate variability.[73] Social, biological, and economic factors such as population immunity, housing conditions, mosquito control measures, local ecological environments (vegetation, irrigation system) and drug resistance also have a significant impact on the transmission of dengue. Research outcomes from this study may be used to assist public health decision making and environmental health risk management. Early warning based on forecasts could assist in improving vector control, community intervention and personal protection.

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